Report of the Astronomy and Astrophysics Advisory Committee

March 15, 2012

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March 15, 2012

Dr. Subra Suresh, Director
National Science Foundation
4201 Wilson Blvd., Suite 1205
Arlington, VA 22230

Mr. Charles F. Bolden, Jr., Administrator
Office of the Administrator
NASA Headquarters
Washington, DC 20546-0001

Dr. Steven Chu, Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

The Honorable John D. Rockefeller, IV, Chairman
Committee on Commerce, Science and Transportation
United States Senate
Washington, DC 20510

The Honorable Jeff Bingaman, Chairman
Committee on Energy & Natural Resources
United States Senate
Washington, DC 20510

The Honorable Ralph Hall, Chairman
Committee on Science, Space and Technology
United States House of Representatives
Washington, DC 20515

Dear Dr. Suresh, Mr. Bolden, Secretary Chu, Chairman Rockefeller, Chairman Bingaman, and Chairman Hall:

I am pleased to transmit to you the annual report of the Astronomy and Astrophysics Advisory Committee for 2011–2012.

The Astronomy and Astrophysics Advisory Committee was established under the National Science Foundation Authorization Act of 2002 Public Law 107-368 to:

(1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy;

(2) assess, and make recommendations regarding, the status of the activities of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy as they relate to the recommendations contained in the National Research Council's s 2001 report entitled Astronomy and

Astrophysics in the New Millennium and the recommendations contained in subsequent National Research Council reports of a similar nature;

(3) not later than March 15 of each year, transmit a report to the Director, the Administrator of the National Aeronautics and Space Administration, the Secretary of Energy, the Committee on Commerce, Science and Transportation of the United States Senate, the Committee on Energy and Natural Resources of the United States Senate, and the Committee on Science, Space, and Technology of the United States House of Representatives, on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

The attached document is the ninth such report. The executive summary is followed by the report, with findings and recommendations for NSF, NASA and DOE regarding their support of the nation's astronomy and astrophysics research enterprise, along with detailed recommendations concerning specific projects and programs.

I would be glad to provide you with a personal briefing if you so desire.

Sincerely yours, on behalf of the Committee,

Sarah E Church

Sarah Church
Chair, Astronomy and Astrophysics Advisory Committee

cc:

Senator Kay Bailey Hutchison, Ranking Member, Committee on Commerce, Science and Transportation, United States Senate

Senator Lisa Murkowski, Ranking Member, Committee on Energy & Natural Resources United States Senate

Representative Eddie Bernice Johnson, Ranking Member, Committee on Science, Space, and Technology, United States House of Representatives

Senator Bill Nelson, Chairman, Subcommittee on Science and Space, Committee on Commerce, Science and Transportation, United States Senate

Senator John Boozman, Ranking Member, Subcommittee on Science and Space, Committee on Commerce, Science and Transportation, United States Senate

Senator Maria Cantwell, Chairwoman, Subcommittee on Energy, Committee on Energy & Natural Resources, United States Senate

Senator James Risch, Ranking Member, Subcommittee on Energy, Committee on Energy & Natural Resources, United States Senate

Senator Barbara Mikulski, Chairwoman, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate

Senator Kay Bailey Hutchison, Ranking Member, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate

Senator Dianne Feinstein, Chairwoman, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate

Senator Lamar Alexander, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate

Representative Rodney Frelinghuysen, Chairman, Subcommittee on Energy and Water Development, Committee on Appropriations, United States House of Representatives

Representative Peter J. Visclosky, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, United States House of Representatives

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Dr. Carl Wieman, Associate Director, Science Division, Office of Science and Technology Policy, Executive Office of the President
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Dr. Thomas Statler, Program Director, Division of Astronomical Sciences, National Science Foundation
Dr. Tamara Dickinson, Senior Policy Analyst, Office of Science and Technology Policy, Executive Office of the President
Dr. Gerald Blazey, Assistant Director, Physical Sciences, Office of Science and Technology Policy, Executive Office of the President
Dr. J.D. Kundu, Program Examiner, NASA, Office of Management and Budget
Dr. Joel Parriott, Program Examiner, NSF, Office of Management and Budget
Dr. Arti Garg, Program Examiner, DOE, Office of Management and Budget

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Dr. Stefi Baum, Rochester Institute of Technology
Dr. Sarah Church, Stanford University

Dr. Debra Elmegreen, Vassar College
Dr. Joshua Frieman, Fermilab
Dr. Martha Haynes, Cornell University
Dr. Gregory Laughlin, University of California, Santa Cruz
Dr. Mordecai-Mark Mac Low, American Museum of Natural History
Dr. Richard Matzner, University of Texas, Austin
Dr. Paul Vanden Bout, National Radio Astronomy Observatory
Dr. John Wefel, Louisiana State University
Dr. Brian Winer, The Ohio State University
Dr. Charles Woodward, University of Minnesota

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Executive Summary

The Astronomy and Astrophysics Advisory Committee (AAAC) advises the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE) on selected issues within the fields of astronomy and astrophysics that are of mutual interest and concern to the agencies. Established in the NSF Authorization Act of 2002, the AAAC is chartered to assess and make recommendations regarding coordination of astronomy programs of the NSF, DOE, and NASA, to assess and make recommendations regarding the activities of the agencies related to National Research Council Astronomy and Astrophysics Decadal Surveys, and to report their assessments and recommendations annually to the NSF Director, the NASA Administrator, the Secretary of Energy, and to the relevant committees in the House and Senate.

This communication represents our annual report. Our findings and recommendations related to our charter are given below. We have indicated the appropriate section in the main report where further discussion of each item may be found.

Findings and Recommendations

- The awarding of the 2011 Nobel Prize in Physics for the discovery of the cosmic acceleration is a tremendous achievement for U.S. science. The AAAC notes that NSF, DOE, and NASA all contributed to making this great discovery possible. This is an outstanding demonstration of the benefits of coordination among the three agencies (§1.1).
- The AAAC lauds the agencies for their efforts to implement the program laid out in the 2010 NRC decadal survey on astrophysics, *New Worlds, New Horizons in Astronomy and Astrophysics* (NWNH) and for their adherence to the prioritization of the projects laid out in NWNH. However, severely constrained budgets are delaying the implementation of many of the NWNH recommended projects. The AAAC is concerned about the impact of these constraints on the ability of the U.S. to maintain its scientific and technical leadership (§2).
- The rigorous re-baselining of the James Webb Space Telescope (JWST) budget and management should lead to better budget and schedule control, and increases the confidence that the project will be completed on the re-baselined budget and schedule, which are $8.0B to launch and a 2018 launch, respectively. The AAAC applauds this new plan while at the same time urging NASA to do everything possible to continue a healthy balanced program of large, medium, and small-scale projects while still fully supporting JWST (§2.1).
- The Large Synoptic Survey Telescope (LSST), the top-ranked large ground-based facility in NWNH, is on the path to being started, with an active NSF/DOE Joint Oversight Group (JOG) to synchronize the approval, review and funding processes. The AAAC applauds NSF and DOE for their coordinated activities and finds that it is very important that these activities remain synchronized as the project proceeds (§2.2).
- The Science Definition Team (SDT) for the Wide Field InfraRed Survey Telescope (WFIRST), the top-ranked large-scale space-based mission of NWNH, is planning two design reference missions, one that continues the mission design as a stand-alone observatory and the other avoiding duplication of capabilities with LSST and the European Space Agency (ESA)-led Euclid mission. The NASA budget projections preclude investment in future large missions until JWST launches, putting WFIRST on a course to launch no sooner than the middle of the next decade. The AAAC was pleased to hear of the plans for the design

reference missions but is concerned that the lack of other investment in WFIRST and the subsequent delayed launch could jeopardize its utility (§2.3).

- The AAAC is concerned about the delay in the implementation of a Mid-Scale Innovations program in NSF, which was identified by NWNH as the second priority for the ground-based program (after LSST) this decade. Moreover, the current budgetary constraints have severely curtailed the ability of NSF AST to respond to *any* unsolicited mid-scale proposals in FY 2012. The AAAC is alarmed with this curtailment, which impacts the ability of NSF to respond to proposals that address NWNH science priorities (§2.5).
- The AAAC is concerned about the long-term health of ground-based astronomy due to decreasing budgets in the NSF Astronomy and Astrophysics Research Grants (AAG) and the Advanced Instrumentation and Technologies (ATI) program (§2.6).
- The NSF Division of Astronomical Sciences (AST) is in the process of carrying out a Portfolio Review, as recommended in NWNH. The AAAC commends this activity and eagerly anticipates the Portfolio Review report and the resulting AST implementation plan (§2.7).
- The AAAC is concerned about declining levels of funding for technology development within NASA, NSF, and DOE. Maintaining technology development is essential to enable the discoveries that will take place in future decades, and to maintain the technical leadership of the U.S. (§2.8).
- The AAAC was informed that NSF Division of Astronomical Sciences (AST) is undergoing a Congressionally mandated down-select of a Giant Segmented Mirror Telescope (GSMT), although there is currently no possibility of Federal investment in this 3rd-ranked NWNH large-scale ground-based priority before at least 2020, if then (§2.9).
- The AAAC endorses the need to enter into the new Gemini partnership arrangement in a manner which satisfies the international partners and which at the same time, better meets the scientific needs of the U.S. community and reflects the increased share of U.S. involvement (§2.10).
- The AAAC encourages continuing dialog and planning among the Virtual Astronomical Observatory (VAO), major U.S. astronomical survey teams, and national observatories to ensure the curation, distribution, and access to legacy astronomical datasets and the development of common standards, pipelines and tools that will enable their full use for scientific research, education and outreach (§2.12).
- The Committee on Astronomy and Astrophysics (CAA) is in the process of being formed by the National Research Council (NRC), following discussions with NASA and NSF. This fulfills the NWNH recommendation that a Decadal Survey Implementation Advisory Committee be formed to provide strategic advice on decadal report-related issues and to monitor the progress on achieving the recommendations. The AAAC notes that the strategic role of the CAA complements the AAAC, which has a more tactical role and an emphasis on interagency coordination (§2.16).
- Interagency coordination and interactions on a number of joint projects including the LSST, the Theory and Computation Networks (TCN), Fermi and the Dark Energy Survey (DES) are good. The AAAC is pleased with the level of such cooperation (§3).

- The AAAC finds that several new ground-based observatories have been commissioned or have completed major upgrades this year, including ALMA (§1.5), EVLA (§1.6, now renamed the Karl G. Jansky VLA) and the new Gemini adaptive optics system (GeMS, §1.8).
- The AAAC finds that the Stratospheric Observatory for Infrared Astronomy (SOFIA) is advancing toward mission maturity and has demonstrated early scientific return. The AAAC recommends that NASA provide timely updates to the committee and its other advisory apparatus as this activity proceeds. (§1.9).
- The AAAC expresses its continuing concern that U.S. inventories of mission critical consumables including Plutonium-238, Helium-3, and Helium-4, which enable a range of astrophysics research as well as commercial and national security endeavors, are depleting rapidly (§4.2).
- The AAAC finds that Federal investment in the enterprise of astronomy continues to enhance our nation's capacity to innovate, educate, and build, and thus our economic security, our international competitiveness, and our world leadership in science, engineering, and technology (§5).

Astronomy and Astrophysics Advisory Committee Report
March 15, 2012

The following constitutes the annual report of the Astronomy and Astrophysics Advisory Committee (AAAC) for 2011-2012. The role of the AAAC is 1) to monitor the coordination of astronomy and astrophysics across three Federal agencies: DOE, NASA, and NSF, 2) to monitor the status of activities contained in the relevant National Research Council (NRC) decadal survey reports, and 3) to report on our findings by March 15 each year.

The committee met four times between March 2011 and March 2012. There were face-to-face meetings, held at the NSF, on October 13-14, 2011 and February 10-11, 2012, and teleconferences on May 6, 2011 and March 2, 2012. The committee received briefings from each of the agencies, and was pleased to engage in discussions with the Office of Management and Budget, and the Office of Science and Technology Policy, at the February 2012 meeting. A major focus of the committee this year has been to understand how the agencies are implementing the recommendations from the 2010 NRC decadal survey on astrophysics, *New Worlds, New Horizons in Astronomy and Astrophysics* (NWNH). In this report we have highlighted the achievements in the last year, and findings and recommendations regarding agencies activities.

1. Science Highlights

Finding: The awarding of the 2011 Nobel Prize in Physics for the discovery of the cosmic acceleration is a tremendous achievement for U.S. science. The AAAC notes that NSF, DOE, and NASA all contributed to making this great discovery possible. This is an outstanding demonstration of the benefits of successful cooperation among the three agencies.

Finding: The AAAC finds that several new ground-based observatories have been commissioned or have completed major upgrades this year, including ALMA, EVLA (now renamed the Karl G. Jansky VLA) and the new Gemini adaptive optics system (GeMS).

The past year has seen some exciting achievements for the U.S. astronomical community including the awarding of the 2011 Nobel Prize for the discovery of cosmic acceleration, the discovery of Earth-sized planets by the Kepler experiment, and the first images from observatories such as ALMA, the Karl G. Jansky Very Large Array (Jansky VLA), and the new adaptive optics system on Gemini, that will significantly extend the facilities available to U.S. astronomers. A number of these achievements are highlighted below.

1.1. Nobel Prize for the Discovery of Cosmic Acceleration

The 2011 Nobel Prize in physics was awarded to Saul Perlmutter, Adam Riess and Brian Schmidt for the discovery of cosmic acceleration, and its implications for the existence of dark energy. Quoting from the Nobel Prize press release: "In 1998, cosmology was shaken at its foundations as two research teams presented their findings…the two research teams found over 50 distant supernovae whose light was weaker than expected - this was a sign that the expansion of the Universe was accelerating. The acceleration is thought to be driven by dark energy, but what that dark energy is remains an enigma - perhaps the greatest in physics today. What is known is that dark energy constitutes about three quarters of the Universe. Therefore the findings of the 2011 Nobel Laureates in Physics have helped to unveil a Universe that to a large extent is unknown to science. And everything is possible again."

The discovery of cosmic acceleration is great success story for science, and a great success story for U.S. science funding. This research was predominantly supported by the three agencies under the AAAC purview: DOE, NASA, and NSF. In a presentation to the AAAC one of the Nobel Laureates, Saul Perlmutter, called out the responsiveness and ambitious nature of U.S. science funding as factors that made this great discovery possible, and urged all concerned to nurture and steward these strengths of our system as we look to the future.

1.2. Nearby Supernova Discovered with the Palomar Transient Factory

The Nobel-prize winning discovery of cosmic acceleration was enabled by the measurement of distances to Type 1a supernova explosions, which often vastly outshine their host galaxies. The joint NSF-DOE funded Palomar Transient Factory recently discovered a supernova in the nearby Pinwheel Galaxy (Figure 1). Because this galaxy is so close to our own, and because the supernova was discovered within hours of the first moments of the explosion, scientists will be able to learn a great deal about the underlying mechanism of these types of supernovae, which has potential implications for the accuracy of future dark energy measurements based on supernova measurements.

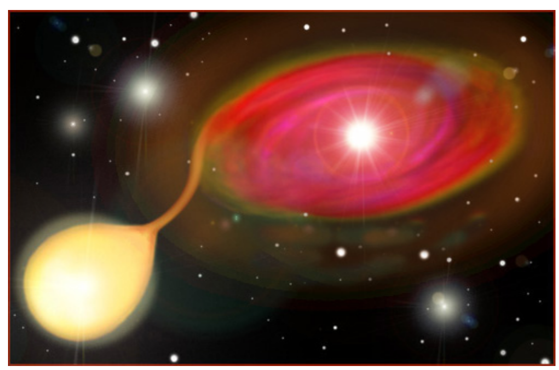

Figure 1: (Left): supernova SN 2011fe, discovered in the Pinwheel Galaxy by the Palomar Transient Factory (Credit: B. J. Fulton, Las Cumbres Observatory Global Telescope Network). (Right): Artist's illustration[1] of a type-1a supernova, which occurs when a dense white dwarf orbiting a star accretes enough matter from its companion to trigger a massive explosion.

1.3. Kepler Discovers Earth-sized Planets in Earth-like Orbits

The NASA Kepler Mission has continued to operate smoothly and to provide stunning results that are changing our understanding of how planetary systems form. A major highlight from the past year was the discovery of the first *circumbinary* planet – Kepler 16-b, a Saturn-sized world

[1] from http://www.lbl.gov/Science-Articles/Archive/sabl/2007/Nov/darkenergy2.html

that orbits a pair of low-mass stars, and that has been observed in transit across both members of the binary pair. Kepler is pushing inexorably into the regime of true-Earth analogs – Earth-sized planets in Earth-like orbits about their parent stars. Indeed, the discovery of Kepler 20e and Kepler 20f mark the first detections of Earth-sized planets, and Kepler 22b represents the first detection of a transiting super-Earth sized planet within the habitable zone of its solar-like host star.

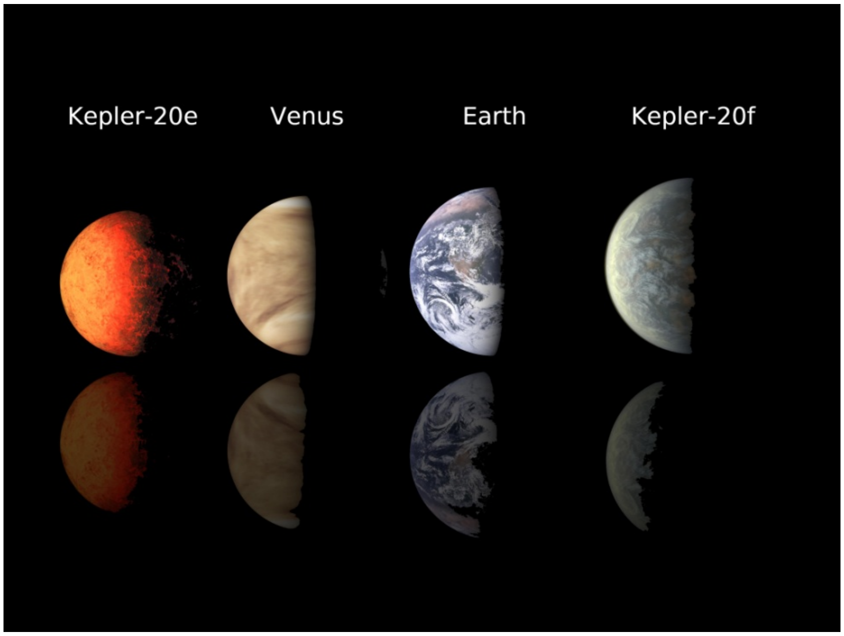

Figure 2: Artist's impression of two Earth-sized planets, Kepler 20e and 20f, discovered by Kepler. Images of Earth and Venus are shown for comparison. (Credit: NASA/Ames/JPL-Caltech)

In addition to these particular highlights, Kepler is also making profound discoveries that provide the basic characterization of the galactic planetary census. In the latest release of data, the Kepler team reports more than 2,300 planet candidates, or "objects of interest", the vast majority of which are likely to be bona-fide planets. This profusion of worlds is consistent with the recent realization that, in the solar neighborhood, at least 50% of a class of main-sequence dwarf stars known as chromospherically-quiet are accompanied by a planet, or in many cases, multiple planets. These planets typically have masses less than 30 Earth masses and orbital periods less than 100 days.

1.4. Massive Black Holes

Two ten-billion-solar-mass black holes, discovered at the centers of giant elliptical galaxies, exceed predictions from an extrapolation of previously known scaling relations of black hole masses, suggesting a new evolutionary process. A paper published in *Nature* in December 2011 described this discovery in work supported by NASA and NSF. Observations conducted over the last few decades indicate that all massive galaxies have supermassive black holes at their centers. The giant elliptical galaxy Messier 87 hosts the previously most massive known black hole; it has a mass of 6.3 billion solar masses. Astronomers have discovered scaling laws that predict the central black hole mass based on the luminosity of the stars, or on the velocity of stars orbiting in a galaxy. The work published in Nature found that NGC 3842, the brightest galaxy in a cluster at a distance from Earth of 320 million light years, has a central black hole with a record-breaking mass of 9.7 billion solar masses, and that a black hole of comparable or even greater mass is present in NGC 4889, the brightest galaxy in the Coma cluster (at roughly the same distance). These two black holes are significantly more massive than predicted by the scaling laws known to date. Although the scaling laws remain useful for predicting black hole masses in less massive elliptical galaxies, these new measurements suggest that different evolutionary processes may determine the growth of the largest galaxies and their black holes.

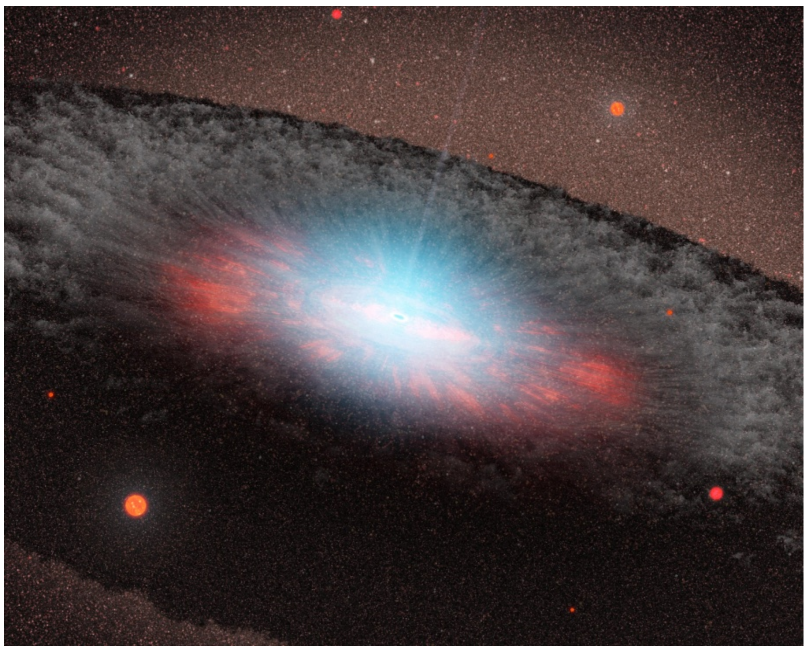

Figure 3: This artist's concept depicts a supermassive black hole at the center of a giant elliptical galaxy. The blue color here represents radiation pouring out from material very close to the black hole. The grayish structure surrounding the black hole, called a torus, consists of gas and dust. Beyond the torus, only the old red-colored stars that make up the galaxy can be seen. (Credit: NASA/JPL-Caltech: http://photojournal.jpl.nasa.gov/catalog/PIA08696)

1.5. Early Science From the Atacama Large Millimeter/Submillimeter Array

During the last year, progress on the construction of the Atacama Large Millimeter/Submillimeter Array (ALMA) has accelerated with delivery of two antennas per month; the major U.S. effort is scheduled for completion in fall 2012. Even before its completion, the availability of a first set of antennas has enabled the undertaking of early science using its unique capability, yielding an unprecedented view of the gas and dust in the colliding “Antennae” galaxies (Figure 4). This test image, made with only 16 antennas, already exceeds the quality and detail of all previously available images and shows that galaxy interactions trigger the compression of gas clouds and the formation of new generations of stars in both the galaxies and the tidal tails caused by the interaction. The full ALMA array consisting of 66 telescopes is expected to be complete in 2013.

Figure 4: Multi-wavelength composite of the interacting Antennae galaxies showing star-forming regions traced by millimeter and submillimeter wavelength radio emission detected by ALMA (orange and yellows) in greater detail than ever before seen, superposed on longer wavelength radio emission from cold gas detected by the Very Large Array radio (blues), and both young and older stars in optical images from the Hubble Space Telescope and Cerro Tololo Inter-American Observatory (Credit**:** NRAO/AUI/NSF; ALMA (ESO/NAOJ/NRAO); HST (NASA, ESA, and B. Whitmore (STScI)); J. Hibbard, (NRAO/AUI/NSF); NOAO/AURA/NSF).

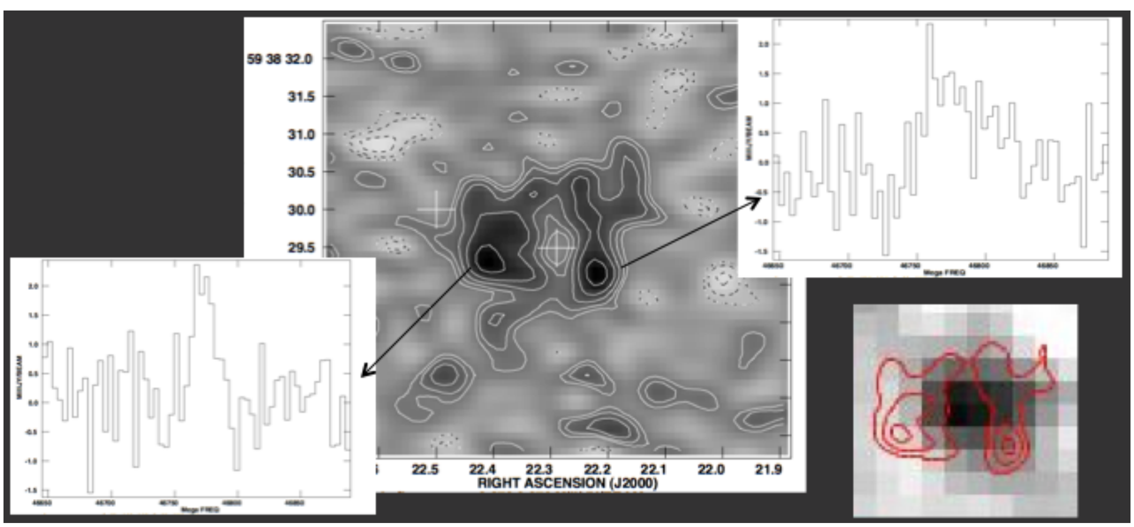

Figure 5: Map[2] of emission from carbon monoxide in a galaxy that formed when the universe was only 1.6 billion years old. This map was made with the new Karl G. Jansky VLA.

2 from https://science.nrao.edu/science/highlights/images/a-molecular-einstein-ring../view

1.6. The Karl G. Jansky Very Large Array

The National Radio Astronomy Observatory's Very Large Array, supported by the NSF, has been renamed the Karl G. Jansky Very Large Array (Jansky VLA) both to honor the founder of radio astronomy and to mark a significant upgrade to the capabilities of this telescope (formerly known as the Expanded Very Large Array, or EVLA, project). The Jansky VLA has been used to map the carbon monoxide (CO) in a galaxy at a redshift of 3.93, when the universe was only 1.6 billion years old (Figure 5). The galaxy was discovered via its submillimeter emission and is also visible at optical and near-infrared wavelengths. The brightness of the radio line emission is greatly increased because the molecular gas is viewed through the gravitational field of a galaxy lying directly in front of it, which bends the light from the distant galaxy as it travels towards us. The ring-like appearance of the molecular gas is caused by the exact alignment of the foreground "gravitational lens" and the background "lensed galaxy" and is known as an "Einstein ring".

1.7. Recent Results from Fermi

The Fermi Gamma-ray Space Telescope (FGST) is a highly successful joint mission between DOE and NASA that explores some of the most energetic phenomena in the cosmos. Launched in 2008, FGST has reported a wide range of exciting astrophysical measurements.

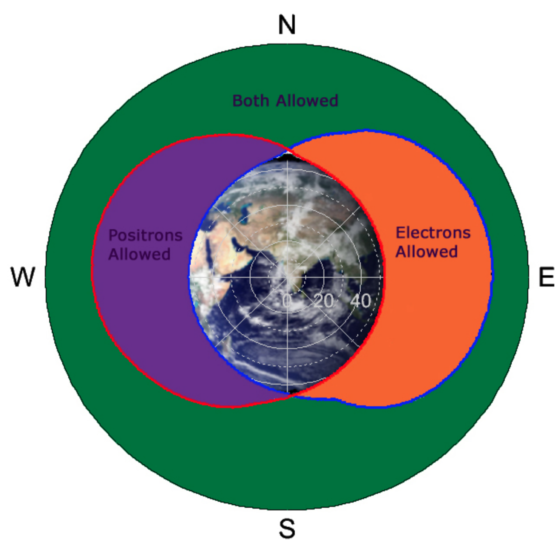

Figure 6: FGST scientists used the Earth's shadow created by its magnetic field to make separate observations of electrons and positrons. The measurement indicates a larger than expected flux of positrons (antimatter). (Credit: J. Vandenbroucke, Fermi-LAT collaboration).

One particularly exciting result from the last year was the measurement of the relative abundance of high-energy electrons and positrons via a novel technique that used the Earth's magnetic field (Figure 6). This measurement revealed a remarkable increase in the number of observed positrons, which are members of a class of exotic particles know as antimatter; the cause for the larger than expected number of these particles in our galaxy is being debated. FGST scientists have also continued their search for dark matter by using observations of small galaxies near to our own Milky Way galaxy. Small galaxies are expected to be rich in dark matter and these studies are beginning to place strong limitations on possible theoretical models for dark matter. FGST observations probe the universe far beyond our galaxy and even neighboring galaxies. Last year, the FGST team released a catalogue of distant galaxies that were identified because they are emitting tremendous amounts of energy from their central cores.

The successful development and operation of FGST was recognized by the American Physical Society this past year when William Atwood was awarded the 2012 W.K.H. Panofsky Prize "for his leading work on the design, construction, and use of the Large Area Telescope (LAT) on the Fermi Gamma-ray Satellite, enabling numerous new results in gamma-ray astrophysics and fundamental physics." The High-Energy Division of the AAS has also recognized Atwood's work with the 2011 Rossi prize, which he shares with Peter Michelson (LAT Principal Investigator) and the LAT Team.

1.8. New Adaptive Optics Techniques Implemented at the Gemini-South Telescope

In 2011 the international Gemini Observatory successfully implemented the Gemini Multiconjugate Adaptive optics System (GeMS) on the Gemini-South telescope on Cerro Pachón, Chile. Adaptive optics techniques are used to mitigate the effect of atmospheric scintillation (the "twinkling" of stars), which has hampered the ability to study the cosmos from the ground as the celestial images are blurred by distortions in the atmosphere. The technique, first suggested in the 1950's and developed by Horace Babcock at the Mt. Wilson Observatories, mitigates the distortion of the Earth's atmosphere by rapidly correcting the optical surfaces of telescopes to sharpen the images using the light from "guide-stars" detected by light-wave sensors in real time. Adaptive optics systems have been deployed on select ground-based telescopes since the early 1980s, enabling new views of the sky. However, the scale of the first-generation correction has been quite limited to small fields of view (the patch of sky observed) where suitable bright guide stars are available.

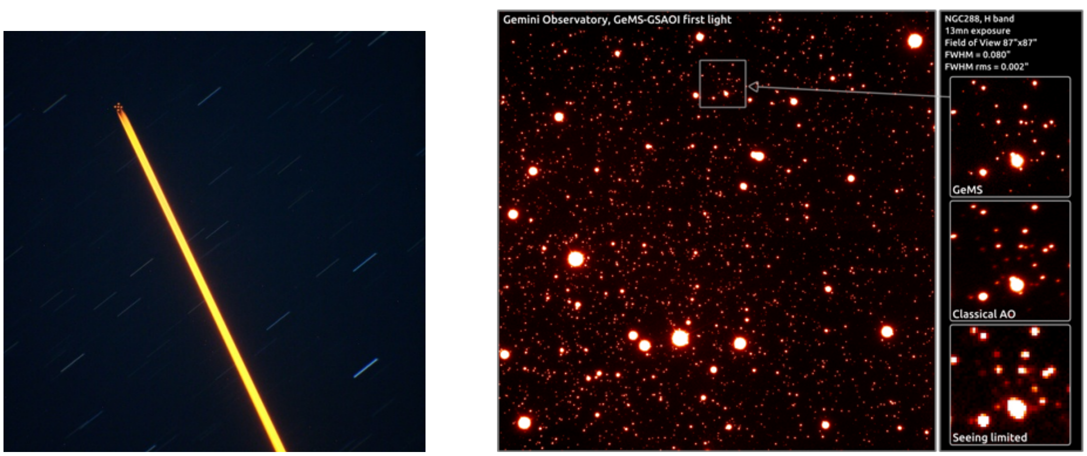

Figure 7: (Left): The Gemini South laser guide star "constellation" shows the 50-watt laser beam shining upward toward the atmospheric sodium layer about 90 kilometers above the earth's surface. (Right): Gemini South's "first light" image from GeMS/GSAOI shows extreme detail in the central part of the globular star cluster NGC 288. The image, taken at 1.65 microns, has a field-of-view 87 x 87 arcseconds. The average full-width at half-maximum is slightly below 0.080 arcsecond, with a variation of 0.002 arcsecond across the entire field of the image. Insets on the right show a detail of the image (top), the same region observed with classical adaptive optics (middle), and seeing-limited observations (bottom) with no correction. (Credit: Gemini Observatory/AURA)

The success of the GeMS capability represents a revolutionary leap in this technique. Using GeMS, Gemini has demonstrated that the adaptive optics approach can be applied over 10 times wider fields-of-view, while extending the breadth of the visible sky over which this technique can be used. It achieves this by generating a constellation of artificial guide-stars using new technology lasers (Figure 7). GeMS delivers ultra-sharp images over the entire field of view to science instruments by using tomographic atmospheric techniques (adapted from medical imaging), three deformable mirrors driven by hundreds of small actuators, and an array of super-computers. GeMS will open new discovery space for ground-based astronomical observations that will exploit the unprecedented spatial resolution and image quality to reveal the cosmos unblurred by the Earth's atmosphere. Successful demonstration of this cutting-edge technology on Gemini also provides a critical pathway that will enable the next generation 20-30m class facilities envisaged in NWNH to accomplish the science laid out in NWNH.

1.9. The Stratospheric Observatory for Infrared Astronomy

Finding: The AAAC finds that the Stratospheric Observatory for Infrared Astronomy (SOFIA) is advancing toward mission maturity and has demonstrated early scientific return. The AAAC recommends that NASA provide timely updates to the committee and its other advisory apparatus as this activity proceeds.

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is an international collaboration between NASA and the German Aerospace Center DLR with primary flight operations conducted out of the Dryden Aircraft Operations Facility in Palmdale, California. A science center and mission operations center is based at NASA Ames Research Center at Moffett Field, California, which manages SOFIA in concert with the Universities Space Research Association (USRA, Colombia, Maryland) and the German SOFIA Institute (DSI, Stuttgart). This airborne astronomy platform comprises a 2.5-m telescope facility in a specially modified 747SP aircraft that operates at altitudes in excess of 40,000ft where the atmospheric absorption due to water in the terrestrial atmosphere is greatly diminished. This allows SOFIA to make observations at wavelengths longward of the optical regime in transparency windows that are inaccessible from the ground.

The AAAC was apprised by NASA that SOFIA achieved a number of mission milestones in 2011 including successful commissioning of the telescope and initial science verification flights of facility instruments, execution of peer-reviewed U.S. community science demonstration flights, and participation of 26 "Airborne Astronomy Ambassadors" in flights drawn from a yearly professional development opportunity extended to educators through a competitive, peer-reviewed process (§5).

The AAAC was informed that initial science observations conducted during the early commissioning phase of SOFIA are demonstrating the new frontiers opened by this mission (Figure 8). The SOFIA Science Center has also established a presence within the U.S. community as a locus of expertise in airborne astronomical capability, successfully completing the first announcement of opportunity for community wide science (Cycle 1) that was oversubscribed by a factor of 10 compared to the number of available flight hours. A solicitation for second-generation instruments has been issued through a NASA Stand Alone Missions of Opportunity Notice (SALMON).

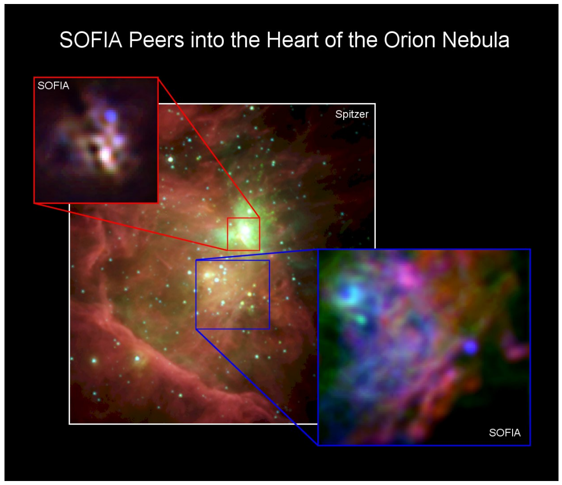

Figure 8: The two inset figures show mid-infrared images obtained with the SOFIA and the Faint Object Infrared Camera (FORCAST) of the heart of the Orion nebula star-forming region, also known as Messier 42 (M42), 1500 light-years distant from the Earth. The SOFIA image shows a complex distribution of interstellar dust, composed primarily of silicon, carbon, and other heavy elements, as well as ice and organic molecules. These are the materials from which new stars and planetary systems form. The SOFIA images show infrared emission at wavelengths of 20 (blue), 31 (red), and 37 microns (green) that arise from dust at 200-300 degrees below zero. The background image shows the same area imaged by the NASA Spitzer space telescope. (Credit: SOFIA image – J. De Buizer/NASA/DLR/USRA/FORCAST; Spitzer image – NASA /JPL)

SOFIA is advancing toward mission maturity. The aircraft is currently undergoing a planned major refurbishment of avionics, power distribution systems, interior layout and infrastructure, and telescope cooling capabilities to enhance mission safety, operational efficacy, telescope image quality, and scientific productivity prior to commencing Cycle 1 peer-reviewed science. At this juncture, the committee is not aware of any mission issues that would impede or slow the trajectory of SOFIA to meet the Congressionally mandated goals of achieving routine operations and a full flight manifest of 960 hours per annum by 2014 December.

2. Decadal Projects and Recommendations

Finding: The AAAC lauds the agencies for their efforts to implement the program laid out in the 2010 NRC decadal survey on astrophysics, New Worlds, New Horizons in Astronomy and Astrophysics (NWNH) and for their adherence to the prioritization of the projects laid out in NWNH. However, severely constrained budgets are delaying the implementation of many of the NWNH recommended projects. The AAAC is concerned about the impact of these constraints on the ability of the U.S. to maintain its scientific and technical leadership.

The AAAC was gratified by the commitment of the funding agencies to the priorities of the astronomical community for the next decade as articulated in NWNH. Adherence to these broadly understood and widely supported priorities is essential to the long-term future of astronomical science in the U.S., particularly in the current context of severely constrained budgets. We applaud the activities of the funding agencies that seek to identify actions which, given the current budget outlook, would best enable the realization of the scientific goals of NWNH. Prominent among these activities are the continued progress towards the development of the LSST, identified by NWNH as the top priority for the ground based program, the planned augmentation of the NASA Explorer Program, and the Portfolio Review at NSF, which will provide critically important input to NSF as it plans for implementation of the ground-based NWNH program.

The AAAC is concerned, however, about the impact of delays in the implementation of many parts of the NWNH recommended program. Some examples that we highlight below include the development of the WFIRST satellite and the implementation of a mid-scale innovations program at NSF. The AAAC is also concerned about the impact of tight budgets on the general grants programs at all three agencies, which support innovations for the next decade, and that allow the astronomical community to make use of new and existing facilities and missions.

2.1. The James Webb Space Telescope

Finding: The rigorous re-baselining of the James Webb Space Telescope (JWST) budget and management should lead to better budget and schedule control, and increases the confidence that the project will be completed on the re-baselined budget and schedule, which are $8.0B to launch and a 2018 launch, respectively. The AAAC applauds this new plan while at the same time urging NASA to do everything possible to continue a healthy balanced program of large, medium, and small-scale projects while still fully supporting JWST.

The James Webb Space Telescope (JWST) is a large, infrared-optimized space telescope, whose science goals are aligned with NWNH-identified science priorities for the next decade. JWST will study every phase in the history of our Universe, ranging from the first luminous glows after the Big Bang, to the formation of solar systems capable of supporting life on planets like Earth, to the evolution of our own Solar System. JWST will have a large mirror, 6.5 meters (21.3 feet) in diameter, and a large sunshield, both of which will fold up for launch and open once JWST is in outer space. JWST will orbit the sun about 1.5 million km (1 million miles) from the Earth and is an international collaboration, with the European and Canadian Space Agencies playing a major role.

The AAAC commends Congress and the administration for fully funding JWST with a budget adequate to complete the construction and to successfully launch in 2018. With restructured management and an $8.0-billion dollar (capped) budget to launch, the JWST Project has emerged from a much-needed replanning exercise with a robust schedule and project execution plan and all of its original science promise intact. Technical and programmatic progress has been excellent since the replan exercise, with all instruments on schedule to enter testing this coming year and a major milestone reached with the completion of JWST's mirrors. The AAAC was pleased to see the technical and programmatic progress on JWST and looks forward to continued updates as JWST progresses towards launch in 2018. The committee anticipates that NASA will apply lessons learned from JWST to the implementation of future large missions such as WFIRST that are expected to launch after JWST.

2.2. The Large Synoptic Survey Telescope

Finding: The Large Synoptic Survey Telescope (LSST), the top-ranked large ground-based facility in NWNH, is on the path to being started, with an active NSF/DOE Joint Oversight Group (JOG) to synchronize the approval, review and funding processes. The AAAC applauds NSF and DOE for their coordinated activities and finds that it is very important that these activities remain synchronized as the project proceeds.

The Large Synoptic Survey Telescope (LSST) was identified as the highest-priority, large, ground-based facility in NWNH. It features a multi-Gigapixel, multi-filter digital imaging camera mounted on a new 8.4-meter telescope to be sited at Cerro Pachón in Chile. It will carry out a dedicated, ten-year survey of nearly half of the sky. The primary science goals of LSST are to probe dark energy and dark matter, to map the Milky Way, to provide an inventory of the Solar System including potentially hazardous Near Earth Objects, and to probe the transient optical sky in the time domain. Technical milestones to date include completion of the casting of the primary and tertiary mirrors and blasting for site preparation work, using private funds (Figure 9).

LSST is a U.S.-led, international project with a combination of public and private support. In the U.S., NSF Division of Astronomical Sciences (AST) and DOE High Energy Physics (HEP) are partnering to sponsor the telescope and data management system (NSF) and the imaging camera (DOE), with NSF as the lead agency (the DOE interest in LSST is in advancing the understanding of dark energy). The project successfully passed its NSF Preliminary Design Review in early Sept. 2011 and its DOE review of the camera (LSSTcam) in December 2011. DOE Critical Decision 1 (CD-1) project approval is pending. The agencies have set up a Joint Oversight Group and are continuing to synchronize their different approval, review, and funding, which will be formalized in an interagency Memorandum of Understanding, to be signed soon. The FY13 President's Request for the DOE HEP budget includes funding for LSSTcam as a Major Item of Equipment (MIE). If this budget is approved, and the appropriate Critical Decision approvals are forthcoming, LSSTcam fabrication activities would start in FY 2013. NSF AST is preparing for the National Science Board to consider recommending the project for the Major Research Equipment and Facilities Construction (MREFC) line with a potential start as early as FY14. According to the current LSST Project timeline, this would enable science operations to start in October 2021. The LSST Project Office is now being operated by the Association of Universities for Research in Astronomy (AURA), which has decades of experience in managing federally supported astronomical facilities.

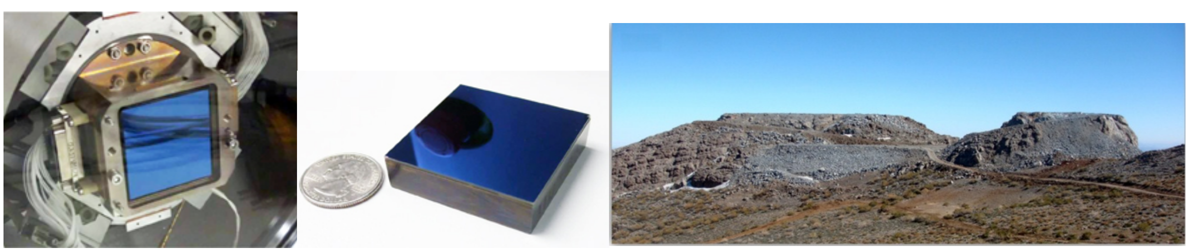

Figure 9: (left and center): Prototype arrays developed for the LSST camera (Credit: LSST/BNL). (Right): Preliminary site preparations are currently underway at the LSST site in Cerro Pachón (Credit: LSST Corporation).

The AAAC was very pleased to hear about progress in the implementation of LSST over the last year, as it represents a bright spot in the implementation of the NWNH recommendations. LSST will be a unique facility for the astronomy and astrophysics community that will enable transformative science. The committee was particularly gratified to learn of the increased coordination and alignment between NSF and DOE, building in part upon their successful partnership in the Dark Energy Survey (DES) project, and looks forward to continued progress toward project construction. The committee notes that this coordination has allowed NSF- and

DOE-led activities to remain well-synchronized and we urge that this continue so that the project can remain on track.

2.3. The Wide-Field Infrared Survey Telescope

Finding: The Science Definition Team (SDT) for the Wide Field InfraRed Survey Telescope (WFIRST), the top-ranked large-scale space-based mission of NWNH, is planning two design reference missions, one that continues the mission design as a stand-alone observatory and the other avoiding duplication of capabilities with LSST and the European Space Agency (ESA)-led Euclid mission. The NASA budget projections preclude investment in future large missions until JWST launches, putting WFIRST on a course to launch no sooner than the middle of the next decade. The AAAC was pleased to hear of the plans for the design reference missions but is concerned that the lack of other investment in WFIRST and the subsequent delayed launch could jeopardize its utility.

The Wide-Field Infrared Survey Telescope (WFIRST), planned as a 1.5-meter telescope with a wide field-of-view incorporating near-infrared imaging and low-resolution spectroscopy, is the top large-scale space-based recommendation in NWNH. The proposed science scope of WFIRST is both broad and unique, including exoplanet microlensing studies, a survey of the sky at infrared wavelengths, a guest investigator program, and measurements to study dark energy. The AAAC heard that the WFIRST Science Definition Team (SDT) is considering two design reference missions: one that continues the mission design as a stand-alone observatory, for the lowest possible cost to NASA, and the other that takes into account synergies between WFIRST, LSST, and Euclid – a dark energy mission planned by the European Space Agency (ESA) and for which a U.S. role is under consideration (§2.4) – to avoid duplication of capabilities. The various options being considered by the SDT include extending the WFIRST filter cutoff out to 2.5 microns compared with the 2-micron filter cutoff proposed for Euclid. This increase in wavelength will enable WFIRST to conduct baryon acoustic oscillation (BAO) observations over the redshift range of 1.5 to 2.5, continuing well beyond Euclid's proposed limit of redshift 1.5. The SDT is also considering deeper observations than Euclid can achieve.

The AAAC is pleased with the SDT progress and with the effort to avoid duplication with Euclid's capabilities so as to maximize the scientific return. However, NASA reported that there is no plan for further investment in WFIRST until after the launch of JWST. There are no funds in the FY13 budget, or out-years, for programs that directly fund WFIRST technology development; support would be provided through competed programs such as ROSES SAT (Research Opportunities in Space and Earth Sciences Strategic Astrophysics Technology). The AAAC is concerned that the lack of other investment in WFIRST and the subsequent delayed launch could jeopardize its utility. We note that NASA is reviewing the WFIRST science mission and that it is likely the NRC will be involved in reviewing the outcomes in its mid-decadal review, as recommended in NWNH. The AAAC anticipates that this issue will be considered further by the NRC Committee on Astronomy and Astrophysics (CAA, §2.16) as part of its mandate to provide strategic advice on decadal report-related issues and to monitor the progress on achieving the recommendations.

2.4. Euclid

The AAAC notes the release of the recent NRC report entitled "Assessment of a Plan for formal U.S. Participation in Euclid," that articulated a possible mechanism for NASA to partner with ESA on the execution of a dark energy mission. The report recommended that NASA invest of order $20-30M in mission critical hardware in return for U.S. participation on the Euclid mission (planned launch 2019) and advised NASA to negotiate with ESA, on behalf of the community, both a NASA-selected scientist on the Euclid Science Team with full data access and the formal inclusion of his/her team in the Euclid Consortium with full data access (note that several U.S. scientists have already independently joined the Euclid Consortium).

On Feb. 24, NASA Associate Administrator for Science Mission Directorate John Grunsfeld sent a letter to Charles Kennel, Chair of the NRC Space Studies Board, indicating that, consistent with the recommendations of the NRC Euclid assessment report, NASA had sent a letter to ESA proposing to contribute NIR detectors for use in the Euclid instruments in exchange for participation in the Euclid Science Team and Consortium. The letter also noted NASA's intent to undertake discussion with ESA on synergies between Euclid and WFIRST.

International cooperation on Euclid represents an initial step to achieving advances in dark energy research – a key scientific frontier identified in NWNH. NASA engagement with Euclid likely will have derivative implications regarding interagency cooperation between two predominate sources of dark energy research support, the DOE and the NSF, that warrants future consideration by the AAAC.

The AAAC noted that the success of the Euclid mission depends in part on complementary ground-based observations from projects such as LSST and the Dark Energy Survey (DES). The NRC report points out that collaborative processing and analyses of the combined ground-based and space-based datasets in the areas of overlap could position the U.S. community for leadership in their scientific exploitation.

2.5. NSF Midscale Innovations Program

Finding: The AAAC is concerned about the delay in the implementation of a Mid-Scale Innovations program in NSF, which was identified by NWNH as the second priority for the ground-based program (after LSST) this decade. Moreover, the current budgetary constraints have severely curtailed the ability of NSF AST to respond to any unsolicited mid-scale proposals in FY 2012. The AAAC is alarmed with this curtailment, which impacts the ability of NSF to respond to proposals that address NWNH science priorities.

In the category of large ground-based programs, the NWNH recommended as its second priority after LSST, a competed mid-scale innovations program in NSF to bridge the "funding-gap" that currently exists between the Major Research Instrumentation (MRI) program, capped at 4 million dollars, and the MREFC program, which funds projects in excess of ~135 million dollars The NWNH identified a number of potential projects that address NWNH science goals and that would be candidates to compete for funds within such a program. The AAAC recognizes the continued importance of this recommendation and notes, with concern, that in FY12 and FY13, budget constraints preclude the implementation of such a program. Furthermore, in October 2011, NSF AST informed the community that it would be unable to accept *any* unsolicited mid-scale proposals for FY12 (with the exception of design and development funds for CCAT, which was specifically recommended by NWNH as the highest priority mid-scale opportunity). The AAAC is alarmed about the impact of this situation on this important class of projects.

2.6. The NSF Astronomy and Astrophysics Research Grants and Advanced Technology and Instrumentation Programs

Finding: The AAAC is concerned about the long-term health of ground-based astronomy due to decreasing budgets in the NSF Astronomy and Astrophysics Research Grants (AAG) and the Advanced Instrumentation and Technologies (ATI) program.

New discoveries in astrophysics require not only cutting-edge facilities, but also that sufficient resources be available to use them effectively. The Astronomy and Astrophysics Research Grants (AAG) program in NSF AST is the means by which individual investigators are supported to carry out research and training activities with ground-based facilities. The Advanced Technologies and Instrumentation (ATI) program, also part of NSF AST, supports small instrument development for existing facilities, and promising new technologies that require further development before they can be incorporated into new instruments. These programs are also the primary means of support for many graduate students and postdoctoral researchers who provide not only the next generation of investigators, but also a highly trained technical workforce that benefits the U.S. economy. Increases to the funding lines of both AAG and ATI were recommended by NWNH; however, both programs experienced 10-15% cuts in FY12 and are projected to remain flat in the President's FY13 budget request.

The AAAC is very concerned about the continued downward pressure on the AAG and ATI programs. Even in an era of restricted budgets, it is critical to maintain support for these programs. The AAAC urges that NSF AST continue to seek an appropriate balance of facilities and individual grants. The NSF portfolio review (§2.7) will be a key part of that process.

2.7. NSF Portfolio Review

Finding: The NSF Division of Astronomical Sciences (AST) is in the process of carrying out a Portfolio Review, as recommended in NWNH. The AAAC commends this activity and eagerly anticipates the Portfolio Review report and the resulting AST implementation plan.

In response to a substantially more constrained budget outlook compared to that assumed in NWNH, the NSF AST has convened an external Portfolio Review by members of the U.S. Astronomy community[3]. The Portfolio Review committee is charged with recommending a set of critical capabilities needed in the 2015-2025 period that would enable progress on the science program articulated in both NWNH and in the Planetary Decadal Survey, including observational, theoretical, computational, laboratory, research support, work force, and education capabilities. It is also charged with recommending a balance of investments in new and existing facilities, grants programs, and other activities that would deliver those capabilities within several budget scenarios. Importantly, given the extensive deliberations that went into and the broad community consensus behind the Decadal Survey reports, the Portfolio Review is *not* charged with attempting to reorder the Decadal priorities.

The committee has been meeting at least weekly by telephone since September 2011 and has held two face-to-face meetings. NSF AST has solicited community input, and approximately 100 messages were received by the close of the input period (end of January 2012). A third face-to-face meeting is scheduled for April 2012, with the report to be delivered by mid-summer. An AST implementation plan is anticipated later in the Fall, in time for FY14 and later budgets. The AAAC commends NSF AST for carrying out this process and for engaging the community in the process to help shape an optimal program over the next fifteen years. The committee and indeed the entire Astronomy and Astrophysics community eagerly anticipate the Portfolio Review report and the resulting implementation plan.

2.8. Investing in Technological Innovation

Finding: The AAAC is concerned about declining levels of funding for technology development within NASA, NSF, and DOE. Maintaining technology development is essential to enable the

[3] http://www.nsf.gov/mps/ast/ast_portfolio_review.jsp

discoveries that will take place in future decades, and to maintain the technical leadership of the U.S.

Technology development for future ground-based facilities is funded through the NSF ATI program, and for future space missions through the NASA ROSES Strategic Astrophysics Technology (SAT) programs which fund key technologies for specific missions, and through the ROSES Astrophysics Research and Analysis (APRA) program which funds technologies that are suitable for space-based astrophysics but for which a specific mission does not yet exist. The DOE also funds technology development for specific areas that are of interest for the DOE Cosmic Frontiers program.

NWNH emphasized the critical importance of technology development, and recommended augmentations to all of these programs, both to implement NWNH recommendations and also to enable the discoveries of future decades. However, the current budget realities have resulted in cuts to the ATI program (as previously discussed in §2.6) and flat funding for APRA in the proposed NASA FY13 budget. Furthermore, NASA's discontinuation of technology development for WFIRST, the Laser Interferometer Space Antennae (LISA) and the International X-Ray Observatory (IXO), while reasonable given the expected schedule of such missions, will place more pressure on the APRA program, and this is a concern for the long-term health of the field. The AAAC does commend NASA for the implementation of a new program of technology fellowships for early career researchers (the Nancy Grace Roman Technology Fellowships in Astrophysics for Early Career Researchers, §0), but the committee remains concerned about the impact of flat or reduced budgets for technology development on both the future of astronomy and also on the technical leadership of the U.S.

2.9. Giant Segmented Mirror Telescope

Finding: The AAAC was informed that NSF Division of Astronomical Sciences (AST) is undergoing a Congressionally mandated down-select of a Giant Segmented Mirror Telescope (GSMT), although there is currently no possibility of Federal investment in this 3rd-ranked NWNH large-scale ground-based priority before at least 2020, if then.

A Giant Segmented Mirror Telescope (GSMT) is one of the top-ranked large-scale ground-based recommendations of NWNH because of its potential to transform ground-based astronomy and to maintain U.S. leadership in these efforts. As mandated by Congress, NSF AST is conducting a down-select for possible investment in a GSMT project through an open call. The AAAC is satisfied that the NSF is following the recommendations of NWNH in conducting the down-select but notes that due to financial constraints, NSF funds for the selected project would not be available until at least 2020, if then.

2.10. Gemini

Finding: The AAAC endorses the need to enter into the new Gemini partnership arrangement in a manner which satisfies the international partners and which at the same time, better meets the scientific needs of the U.S. community and reflects the increased share of U.S. involvement.

The Gemini Observatory is an international partnership involving the United States, the United Kingdom, Canada, Australia, Chile, Brazil, and Argentina. The partnership has constructed and now operates two 8-meter telescopes: one in the Northern Hemisphere on Mauna Kea, Hawaii, and one in the Southern Hemisphere on Cerro Pachón, Chile. The twin telescopes are infrared-optimized, have superb image quality, and provide unprecedented optical and infrared coverage of the northern and southern skies for astronomical research. With the withdrawal of the United

Kingdom from the partnership, the U.S. share in the partnership will rise from 50% to 63% in 2013. The current international agreement for the operation of the Observatory is scheduled to expire in 2015. The process of negotiating a new partnership agreement is already underway, with the current partners scheduled to state their commitments with respect to the new partnership in November 2012. Consistent with the recommendations made in NWNH, the AAAC endorses the need to enter into the new Gemini partnership arrangement in a manner which satisfies the international partners and which, at the same time better meets the scientific needs of the U.S. community and reflects the increased share of U.S. involvement.

2.11. The Advanced Technology Solar Telescope

The Advanced Technology Solar Telescope (ATST) was one of the top recommendations in the 2000 astronomy and astrophysics decadal survey, whose scientific importance was re-affirmed in NWNH. The committee was dismayed to learn that this long awaited facility has not yet received clearance to break ground and is still in appeals regarding its environmental impact, as was also the case at the time of the AAAC 2011 annual report. While we understand that obtaining such approvals can be a long and arduous process, we hope that the efforts being made can move this project forward expeditiously.

2.12. The Virtual Astronomical Observatory

Finding: The AAAC encourages continuing dialog and planning among the Virtual Astronomical Observatory (VAO), major U.S. astronomical survey teams, and national observatories to ensure the curation, distribution, and access to legacy astronomical datasets and the development of common standards, pipelines and tools that will enable their full use for scientific research, education and outreach.

The 2000 Astronomy and Astrophysics Decadal Survey already anticipated the dawning of a new era of large scale astronomical surveys and their associated data management challenges and data mining opportunities with its recommendation that NASA and NSF collaborate on an initiative to create a "Virtual Observatory" (VO). In the last decade, the agencies supported the development of the VO concept, and the U.S. Virtual Astronomical Observatory (VAO) was established in 2010. The VAO represents a strategic network of initiatives designed to facilitate the distribution and access of astronomical datasets and the tools that enable their use for scientific and educational purposes. The VAO is a leader in the International Virtual Observatory (IVO), working to develop an integrated desktop research environment for worldwide datasets and tools. Within the international effort, the VAO serves as the U.S. node for the certification and registration of quality astronomical datasets. Over the last year, a number of new VAO software tools have been released including a tool to examine the time variation of sources especially to look for periodic behavior, a tool that allows fast positional cross-matching between up to a million sources and common astronomical source catalogs, and a tool to search thousands of astronomical collections which are registered to the VAO. The VAO plays a critical role in the development and stewardship of the infrastructure needed for data management, distribution and access to public datasets, which in turn enables discovery and scientific analysis even beyond the scope of their original purpose.

Continued dialog and planning between the VAO and the major survey teams and national observatories will ensure the curation of legacy astronomical datasets and the development of common standards, pipelines and tools that increase the effectiveness of their distribution, access and utility for scientific research, education, and outreach.

2.13. NASA Explorer Program and Sub-Orbital Program

The AAAC commends the proposal by NASA to augment an Astrophysics Explorer line in order to increase the launch rate to meet the NWNH recommendation for four Explorers and four Missions of Opportunity by the end of the decade, but notes that the proposed implementation has been delayed to FY14 in the President's FY13 budget request. The committee notes the selection of candidate Explorers and Missions of Opportunity from the most recent Explorer competition. These new projects, of course, must successfully complete the study phase, and will be subject to a down-selection before being confirmed as new Explorer flight projects.

The NASA/NSF Long Duration Ballooning project offers flights from McMurdo, Antarctica that achieve altitudes in excess of 120,000 feet, thereby providing access to 'near space' for scientific investigations and new technology development. When the upper altitude winds establish the polar vortex each fall, a balloon can float in that vortex and circumnavigate the continent in 10-14 days. If the winds are steady, a second (and in rare cases a third) circumnavigation is possible. This increases the exposure time for astrophysics payloads by over an order of magnitude compared to a conventional flight within the continental U.S. We commend this example of a very successful inter-agency project with NSF (Office of Polar Programs) providing the logistical support (including the all important 'air resources') and use of the McMurdo facilities, while NASA (Balloon Payload Office, Wallops Flight Facility) provides the payload infrastructure and the launch and flight operations. NASA, NSF, and DOE have all contributed to some of the instruments that have been flown. Moreover, NASA is developing a Super-pressure Balloon that has the potential to increase flight times for experiments by another factor of two to three.

2.14. Research Networks in Theory and Computation

The NWNH report recommended that NSF, NASA, and the DOE cooperate to fund networks in theoretical and computational astrophysics noting, "…a large number of the theoretical challenges posed by the Science Frontiers Panels are of a scale and complexity that require sustained, multi-institutional collaborations of theorists, computational astrophysicists, observers, and experimenters. There is currently no mechanism to support these coordinated efforts at the required level in the United States." As an example of the utility of such computational capabilities in solving complex problems in astrophysics, Figure 10 shows simulations of the formation of the spiral arms in our galaxy.

At its October 2011 meeting, the committee heard that NSF and NASA believe that such a program could be funded despite existing budget constraints, albeit at a reduced level compared to the recommendation of NWNH. The AAAC recognizes as a positive step this effort to implement this recommendation from NWNH. DOE already supports theory and computation activities through several programs within the Office of Science (DOE-SC) and the Office of High Energy Physics (DOE-HEP). Theoretical studies at the Cosmic Frontier are funded as part of the existing Theory subprogram in DOE-HEP and DOE-HEP has already started addressing Cosmic Frontier computing issues via a workshop held in Fall 2011 that assessed the computational challenges involved in DOE-HEP funded Cosmic Frontier research[4].

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[4] The workshop report and talks are available at http://press3.mcs.anl.gov/cosmic-frontier-computing-collaboration/ccr/.

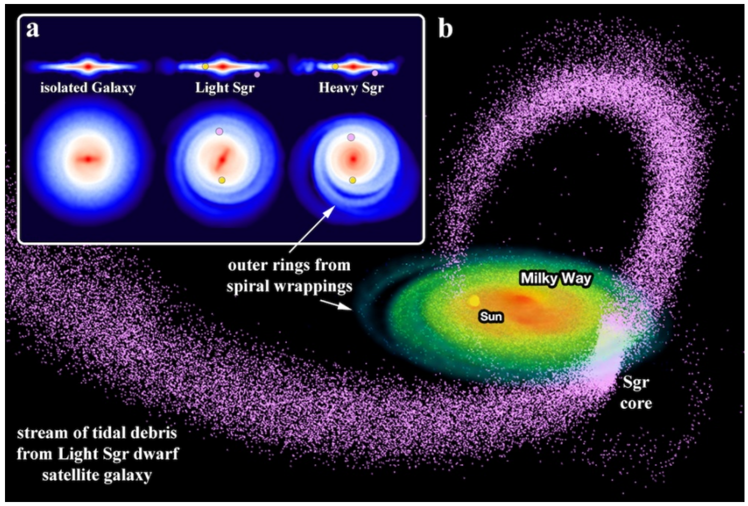

Figure 10: Computer simulations demonstrate that the spiral arms of the Milky Way were formed by its ongoing collision with the Sagittarius (Sgr) dwarf galaxy. The visualizations show the disk of the Milky Way Galaxy for three cases: no impact with a dwarf galaxy, impact with a Sgr dwarf galaxy of lower mass, and impact with a Sgr dwarf galaxy of higher mass. Our Galaxy is shown both edge-on and face-on in the inset panels, the sun's location is marked as a yellow dot, and the present location of the Sagittarius dwarf's remnant core is marked as a pink dot. Shown in the background is a global rendering of the 'light Sgr' tidal debris and the Milky Way disk. (Credit[5]: C.W. Purcell, U Pitt., J.S. Bullock, E.J. Tollerud, M. Rocha, UC Irvine/UC-HIPACC & S. Chakrabarti, Florida Atlantic U.)

2.15. Nurturing the Workforce

The committee finds that, as noted by NWNH, young researchers supported by the federally funded astronomy enterprise continue to provide a pipeline of talent that is well trained to tackle the challenges faced by the nation. The skills that are acquired by astronomy, astrophysics, space science, computer science, and engineering students and postdoctoral researchers working on ground-based projects and space-missions in such diverse areas as advanced instrumentation and large data set management and mining are sought after in a broad range of private and public endeavors. As noted in §2.6 and §2.8, the AAAC is concerned about the budget pressure on individual investigator grants, particularly at the NSF, that traditionally support these young researchers.

As an example of agency endeavors in this area, NASA briefed the AAAC about the Nancy Grace Roman Technology Fellowships in Astrophysics for Early Career Researchers. The goal of this program is both to nurture the next generation of principal investigators for future astrophysics missions and to develop innovative technologies that have the potential to enable major scientific breakthroughs. Fellows receive funding for a one-year concept study to develop a proposal for an advanced technology. A subset of the fellows will then be selected to implement their proposal in a four-year program. The committee commends NASA for this program and looks forward to future briefings about its outcome. In particular the committee would like to hear, at future meetings, about any plans to assess the impact of the down-select process on the fellows, including those unsuccessful in moving to the next phase of the program.

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[5] http://www.news.pitt.edu/news/how-milky-way-got-its-spiral

2.16. Decadal Survey Implementation Advisory Committee

Finding: The Committee on Astronomy and Astrophysics (CAA) is in the process of being formed by the National Research Council (NRC), following discussions with NASA and NSF. This fulfills the NWNH recommendation that a Decadal Survey Implementation Advisory Committee be formed to provide strategic advice on decadal report-related issues and to monitor the progress on achieving the recommendations. The AAAC notes that the strategic role of the CAA complements the AAAC, which has a more tactical role and an emphasis on interagency coordination.

The AAAC was encouraged by the progress toward the formation of a National Academy of Sciences committee to provide strategic advice regarding the recommendations of NWNH, the so-called Decadal Survey Implementation Advisory Committee (DSIAC) of that report. The AAAC heard that NASA funding for the committee, to be called the Committee on Astronomy and Astrophysics (CAA), was in hand and that a funding decision at NSF was imminent. We note the complementary nature of the two committees: the CAA's role will be strategic, while that of the AAAC is more tactical and has an emphasis on interagency coordination.

The CAA will play a particularly important role given the current budget situation and its impact on the implementation of NWNH recommended science, facilities and missions. We expect that the issues that the CAA will consider are likely to include the effect of delays in WFIRST on the timeliness of its science, and the future of missions addressing the LISA and IXO science goals.

3. Interagency Cooperation

Finding: Interagency coordination and interactions on a number of joint projects including the LSST, the Theory and Computation Networks (TCN), Fermi and the Dark Energy Survey (DES) are good. The AAAC is pleased with the level of such cooperation.

The awarding of the Nobel Prize for the discovery of cosmic acceleration, as described in §1.1, is a magnificent demonstration of the benefits of interagency cooperation on scientific problems of mutual interest. Furthermore, the Fermi satellite, discussed in §1.7, continues to be an excellent example of successful cooperation between all three agencies. NASA and DOE built the satellite and instrumentation. NSF-funded contributions include coordinated follow-up of sources, including a large number of millisecond pulsars that have been discovered by combining Fermi data with NRAO Green Bank Telescope measurements. A Fermi-NRAO cooperative arrangement commits observing time on NRAO telescopes for coordinated observations of Fermi sources, to be awarded on a competitive basis. In this section we highlight in more detail other examples of interagency collaboration.

3.1. A Coordinated Ground-Based Approach to the Study of Dark Energy

A number of high priority astronomy and astrophysics projects involve the collaboration of DOE and NSF. The DOE-led DES will use a camera (the Dark-Energy Camera – DECam) developed by DOE with NSF supporting the telescope upgrades, the observing time on the telescope and the data management system. DES is about to start final assembly and will start taking data later this year. The LSST, led by NSF, has passed several design reviews and is slated to compete for funding under NSF's MREFC program. In each case the AAAC finds the collaborative process between the agencies to be exemplary. Each agency is focused on the parts of the project that can be best done with their experience and resources and which fits best with their overall scientific priorities. Furthermore, the agencies have done an excellent job at adapting and combining their respective review processes to enable efficient progress and oversight of each project. The AAAC notes abundant evidence for effective communication between the agencies, which is clearly at the root of these larger successes.

3.2. Ground-Based Tracking of Near Earth Asteroids

On 8 November 2011, Asteroid 2005 YU55, which has a diameter of approximately 400m, passed by the Earth at a distance of about 325,000 km (200,000 miles), the closest known approach of an object this large since a previous asteroid flyby in 1976. Arecibo radar observations made in 2010 when the object was 2.3 million km away showed the asteroid to be almost spherical in shape and slowly spinning (Figure 11). Although 2005 YU55 is in an orbit that regularly brings it to the vicinity of Earth (as well as near Venus and Mars), the 2011 encounter with Earth is the closest it has come to our planet for at least the last 200 years. While the Arecibo Observatory is a facility of the NSF, NASA supports its planetary radar program.

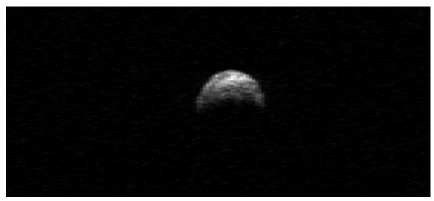

Figure 11: Radar image of Asteroid 2005 YU55 during its close path by the Earth. (Credit: NASA/Cornell/Arecibo)

3.3. Coordinated Observations of Short-Duration Phenomena

The NSF's Very Long Baseline Array (VLBA) and NASA's Rossi X-ray Timing Explorer (RXTE) were used to probe an outburst from a system including a black hole and its companion. RXTE is designed to monitor and detect bursts of X-ray emission that arise when material is ejected from a binary system containing a black hole and another star. Most of the time, material streams out of the binary at a regular benign pace, but on occasion, as in the case here, a highly energetic ejection occurs, producing a burst of X-ray emission which RXTE then detects. The VLBA has the capability to image and track both the normal stream-like "jets" and superfast, "bullets" of ejected material (Figure 12).

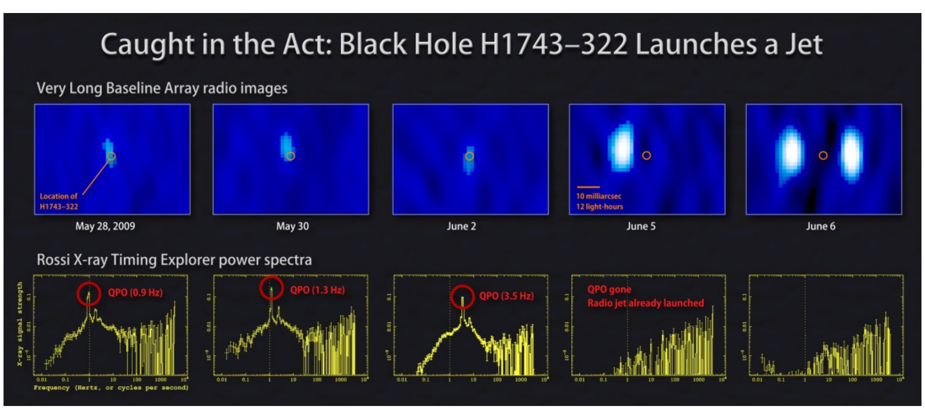

Figure 12: Combined radio (VLBA) and X-ray (RXTE) measurements of an outburst from a black hole and its companion. (Credit: NRAO and NASA/Goddard Space Flight Center)

3.4. Use of VLBA by Other Agencies and International Partners

Current partnerships to support operation of the VLBA include arrangements with: (i) the U.S. Naval Observatory, to support daily geodetic observations using the VLBA in exchange for support of array operations; (ii) the expansion of long-standing cooperative programs with the Max-Planck Institut für Radioastronomie in Bonn, Germany, with recent new programs focused on the enhancement of the VLBA's C-band receiver system to enable far deeper astrometric reach for the VLBA and for the support of array operations, and (iii) expansion of NRAO collaboration with the Academia Sinica Institute for Astronomy and Astrophysics (ASIAA) in Taipei, Taiwan, a North American ALMA partner, on high-frequency interferometry in exchange for partial support of VLBA operations. Additional partnership agreements with other sister observatories are in process.

4. Other Issues

This section summarizes a number of other issues that the committee discussed.

4.1. Big Data

During the past several decades, astronomy has been consistently ahead of the curve in its transition to becoming an all-digital field of science. In connection with this ongoing shift, data volumes and demand for data have been growing exponentially. For example, interest in the Kepler database –served by the Multimission Archive at Space Telescope (MAST) – has been intense, with thousands of users downloading the 200+ Gigabyte Q0-6 public light curves, for a total information transfer to date that is approaching a Petabyte. Looking down the road, appropriate initial mining of the LSST and other instrument databases will require 100+ teraflops of processing power, and will demand 15+ petabytes of rapidly accessible storage capacity. Given the data volume and the computationally intensive nature of many existing and planned projects, it is important that infrastructural issues are addressed early and intelligently, and that optimal cost-effective use be made of emerging computing and storage technologies. The AAAC anticipates that "big data" is an area that is likely to benefit from interagency synergies.

4.2. Scarce Strategic Materials: Plutonium-238, Helium-4, Helium-3

Finding: The AAAC expresses its continuing concern that U.S. inventories of mission critical consumables including Plutonium-238, Helium-3, and Helium-4, which enable a range of astrophysics research as well as commercial and national security endeavors, are depleting rapidly.

The materials Plutonium-238 (Pu-238), Helium-4 (He-4) and Helium-3 (He-3) are individually essential to different aspects of space based astronomy and astrophysics. For reasons specific to each they are becoming expensive, and in some case very difficult to acquire at any price for astronomical research.

- **Plutonium-238 (Pu-238).** The manmade radioactive isotope Pu-238 can be used to generate electricity due to the heat emitted by its radioactive decay. Encapsulated in a radioisotope thermoelectric generator (RTG), this vital element is necessary for powering probes sent to the outer reaches of the solar system, a research area where the U.S. can clearly claim significant international leadership. At present production of this isotope has been stopped. Prompt action is required to again begin producing Pu-238 as it will take about 8 years from initiation to full production of the required 5 kg/year, and the current inventory may be expended by then. Cooperation between the DOE and NASA, with support from the

President and funding from Congress, will be required to fulfill this vital need. The AAAC remains concerned, as we were in our 2011 annual report, that delays in the restart of this production effort hinder not only the ability to conduct NASA planetary missions to the outer solar system, but may well impede development and implementation of future astrophysics missions requiring significant power resources operating in deep space beyond Earth orbit.

- **Helium-4 (He-4).** He-4 is an essential material for very low temperature cooling of astrophysical experiments, providing cooling to one or two degrees above absolute zero, enabling otherwise impossible infrared observations. Helium is also used in the NASA balloon program. There is a shortage of this material. He-4 is coproduced with natural gas, and until recently gas drilling leases included a requirement that the He-4 be captured and deposited in the National Helium Reserve. Currently there is no such requirement, the He-4 is effectively being vented to the atmosphere instead of being captured, and the National Helium Reserve is being depleted, creating a shortage. An administrative change would reverse this unfortunate situation.
- **Helium-3 (He-3).** He-3 is a rare isotope of Helium that is naturally about one hundred thousand times less abundant on Earth than the dominant isotope, He-4. He-3 is a most important isotope in instrumentation for thermal neutron detection. The neutrons react with He-3 to produce charged particles: a proton and a Tritium nucleus, which are easy to detect. He-3 is also used for cooling certain types of astrophysical detectors to temperatures that are only a few hundredths of a degree above absolute zero, temperatures that cannot be achieved with Helium-4 cooling systems. The sole production of technically available Helium-3 is from the refurbishment and dismantlement of the nuclear stockpile since He-3 is a byproduct of the radioactive decay of Tritium in thermonuclear weapons and is separated out and stored during the Tritium cleaning process. This produces a reasonably steady, but limited, resource of the isotope (less than 10,000 STP liters per year). The Department of Homeland Security deploys instruments that detect smuggled plutonium by their neutron emissions, and this has greatly increased pressure on the He-3 supply. There are alternative approaches available to terrestrial systems, while in astrophysical applications there is often no choice.

The AAAC urges that, in consultation with Congress, prompt action be taken and appropriate budgetary resources be identified through cooperative coordination between DOE, NASA, and, if applicable, other federal agencies (e.g., the National Security Agency, Department of Homeland Security), to enable the Pu-238 project production restart, sufficient availability of Helium-3, and a standard procedure to capture Helium-4. All three actions are necessary to assure the viability of future astrophysical observations and experiments.

5. Investment in Astronomy as a National Priority

Finding: The AAAC finds that Federal investment in the enterprise of astronomy continues to enhance our nation's capacity to innovate, educate, and build, and thus our economic security, our international competitiveness, and our world leadership in science, engineering, and technology.

Astronomy is driven by human curiosity. It sparks wonder for the natural world, inspires the imagination of generation after generation of the public, and fires the aspirations of our nation's science, technology, engineering, and mathematics workforce. Astronomy and astrophysics provide tantalizing clues about our universe and about the role of humanity within the cosmos. NWNH outlined an exciting future roadmap to understand our "cosmic dawn": to search for the first stars, galaxies, and black holes, to characterize the growing catalog of new worlds discovered around other stars, to seek nearby, habitable planets, and to explore the fundamental aspects of the universe like dark matter, dark energy, and the accuracy of Einstein's description of gravity (General Relativity) where gravity is strong, as in the environs of merging black holes.

The vision of NWNH is to build on and multiply the success of the past national, international and private investment in astronomy infrastructure, education, outreach, knowledge base, workforce skills, and technology innovation. NWNH thus outlined a balanced program of new activities, mindful of expectations imposed by national budgetary priorities and constraints, to refine and enhance knowledge of our universe. NWNH enumerated the broader contributions of astronomy to society including (but not limited to), (1) engagement of the public in science, (2) improved science literacy and proficiency of school children, teachers, and the public, (3) new technology gateways with applications in medicine, homeland security, energy, and, data-driven science, (4) our understanding of our home planet, the Earth, informing critical fields such as climate science, geology, and asteroid and space monitoring. Further, as detailed by the NWNH, astronomy plays a critical role in all three major elements of the America Competes Act, including frontier research and innovation; strengthened science, technology, engineering mathematics education; and 21st Century workforce development. Thus judicious federal investment in astronomy is needed to achieve the programmatic objectives over the decade of the NWNH decadal survey, to maintain the core capabilities required to realize the scientific return of past investment, and to sustain the national commitment to discovery, and innovation.

As outlined in the America Competes Act, investment in advanced research is key to building America's future. Federal investment in the enterprise of astronomy enhances our nation's capacity to innovate, educate, and build, and thus enhances our economic security, our international competitiveness and our leadership in science, engineering, and technology. It is worth noting that four of the last ten Nobel Prizes in Physics were awarded for astrophysics and related particle physics research, and that in each of the four instances U.S. scientists were recipients of the awards (sometimes shared), underscoring both the forefront nature of astrophysical research and the preeminence of the U.S. in this research. Astronomy is increasingly a global enterprise and international astronomy cooperation and partnerships have innumerable scientific and societal benefits, including leveraging of resources, technology transfer, and inter-governmental cooperation. Insufficient federal funding for American astrophysics would risk the loss of a leadership role for the U.S. on the global astrophysics scene, ceding new discovery and new technology innovation to other countries, and eroding the science and technology accomplishments and prestige of America. Maintaining our nation's leadership in the international scientific arena has clearly understood – as well as completely surprising – benefits for our national society, our culture, the technical literacy and capability of our workforce and for our security. Astrophysics is an important element of our nation's scientific and technology excellence.

Education and Public Outreach (EPO) activities have played an important role in communicating the excitement of new results. Figure 13 shows an example of an ongoing EPO effort, the SOFIA "Airborne Astronomy Ambassadors" program that promotes increased literacy in science, technology, engineering and math by providing hands-on experience to educators that can translate back to classrooms and communities. The AAAC notes that EPO activities at NASA have been scaled back. The committee desires to be briefed in future meetings about the impact of current EPO funding across the agencies on the effectiveness of engagement of the public and K-12 education in the discoveries of existing and future missions.

Figure 13: NASA SOFIA staff scientist Dr. James De Buzier (left) and Dr. Terry Herter, principal investigator of FORECAST (center back) discussing SOFIA science in flight with two educators participating in the SOFIA Airborne Astronomy Ambassadors program, Theresa Paulsen (far right) and Marita Beard (center front). (Credit: NASA/DLR/USRA/SOFIA/N. Veronico)

List of Acronyms

AAAC	Astronomy and Astrophysics Advisory Committee
AAG	Astronomy and Astrophysics Research Grants
ALMA	Atacama Large Millimeter/submillimeter Array
APRA	Astronomy Research and Analysis
ASIAA	Academia Sinica Institute for Astronomy and Astrophysics
AST	Division of Astronomical Sciences
ATI	Advanced Technologies and Instrumentation
ATST	Advanced Technology Solar Telescope
AUI	Associated Universities Inc.
AURA	Association of Universities for Research in Astronomy
CAA	Committee on Astronomy and Astrophysics
CO	Carbon Monoxide
DECam	Dark Energy Camera
DES	Dark Energy Survey
DSIAC	Decadal Survey Implementation Advisory Committee
DLR	German Aerospace Center
DOE	Department of Energy
DOE CD-1	DOE Critical Decision 1
DSI	German SOFIA Institute
EPO	Education and Public Outreach
ESA	European Space Agency
ESO	European Southern Observatory
EVLA	Expanded Very Large Array
FGST	Fermi Gamma-ray Space Telescope
FORCAST	Faint Object InfraRed Camera for the SOFIA Telescope
GeMS	GEmini Multi-conjugate adaptive optics System
GSAO1	Gemini South Adaptive Optics
GSMT	Giant Segmented Mirror Telescope
HEP	High Energy Physics
HST	Hubble Space Telescope
INCITE	Innovative and Novel Computational Impact on Theory and Experiment
IVO	International Virtual Observatory
IXO	International X-Ray Observatory
JPL	Jet Propulsion Laboratory
Jansky VLA	Karl G. Jansky Very Large Array
JWST	James Webb Space Telescope
LAT	Large Area Telescope
LISA	Laser Interferometer Space Antennae
LSST	Large Synoptic Survey Telescope
LSSTcam	LSST camera
MAST	The Multimission Archive at Space Telescope
MIE	Major Item of Equipment
MREFC	Major Research Equipment and Facilities Construction
MRI	Major Research Instrumentation
NASA	National Aeronautics and Space Administration

NOAO	National Optical Astronomy Observatory
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NSF	National Science Foundation
NWNH	New Worlds, New Horizons in Astronomy and Astrophysics
ROSES	Research Opportunities in Space and Earth Sciences
RTG	Radioisotope Thermoelectric Generator
RXTE	Rossi X-ray Timing Explorer
SALMON	Stand Alone Missions of Opportunity Notice
SAT	Strategic Astrophysics Technology
SDT	Science Definition Team
SOFIA	Stratospheric Observatory For Infrared Astronomy
STScI	Space Telescope Science Institute
TCN	Theory and Computational Networks
UC-HIPACC	University of California High-Performance AstroComputing Center
USRA	Universities Space Research Association
VAO	Virtual Astronomical Observatory
VLBA	Very Long Baseline Array
VO	Virtual Observatory
WFIRST	Wide Field InfraRed Survey Telescope